

Aiding Vertical Guidance Understanding

Michael Feary
SJSU/NASA Ames Research Center
mfeary@mail.arc.nasa.gov

Martin Alkin
Federal Express Inc.
mjalkin@fedex.com

Peter Polson
University of Colorado
ppolson@psych.colorado.edu

Daniel McCrobie
Honeywell Inc.
dan.mccrobie@cas.honeywell.com

Lance Sherry
Honeywell Inc.
lance.sherry@cas.honeywell.com

Everett Palmer
NASA Ames Research Center
epalmer@mail.arc.nasa.gov

ABSTRACT

A study was conducted to evaluate training and displays for the vertical guidance system of a modern glass cockpit airliner. The experiment consisted of a complete flight performed in a fixed-base simulator with airline pilots. Three groups were used to evaluate a new flight mode annunciator display and vertical navigation training. Results showed improved pilot performance with training and significant improvements with the training and the Guidance-Flight Mode Annunciator. Using actual behavior of the avionics to design pilot training and FMA is feasible and yields better pilot performance.

INTRODUCTION

A full copy of this study is available on the internet at http://jit.arc.nasa.gov/atrs/98/feary/98-09160/98-09160_feary.pdf.

Studies of pilot understanding about flight deck automation have indicated that pilots are uncomfortable with auto flight systems and that these systems are probably the least understood aspect of automation in modern jets. Wiener [1] provided evidence that identified the autoflight system as one that pilots did not understand well. In his study, 55% of his sample of almost 300 pilots agreed with the following statement: "In the Boeing 757 automation, there are still things that happen that surprise me". About 30% of the pilots agreed with a second statement, "There are still modes and features of the B-757 that I don't understand".

Sarter and Woods [2] replicated Wiener's suggestion that pilots attributed their lowered understanding of vertical guidance to their inability to visualize the vertical path that the airplane was flying, difficulty in predicting vertical navigation behavior, and an incomplete understanding of the system.

The Cockpit System

Current glass cockpit aircraft use annunciation schemes that were designed based on the

displays found in an earlier generation of avionics systems (i.e., DC-10 and B-727). This earlier generation of avionics displayed the results of navigation, control, and stability augmentation tasks only. Because guidance was not automated, it was not annunciated on a cockpit display.

In the latest generation of airplanes, navigation, control, and flight planning tasks are partially annunciated and trained. Adding to the complexity is the integration of the autopilot and autothrottle. These advanced functions need to be understood in a timely manner to be fully utilized. This paper refers to the understanding of the autopilot/autothrottle task as the guidance task.

The *Guidance* task compares the actual position of the aircraft to the current leg of the lateral and vertical flightplan to generate a set of targets and control-modes. Targets include aircraft heading, altitude, speed, flight-path angle, vertical speed, and thrust. Control-modes define the parameters that are controlled to achieve these targets. Lateral axis control-modes, such as heading, adjust the aircraft roll and yaw to maintain the aircraft along a target heading to the next waypoint. Vertical axis control-modes define the position of the elevators and throttles to control the altitude of the aircraft. In current generation aircraft, the control task is annunciated, while the guidance task is not directly annunciated.

Guidance is not treated as a separate topic in training, although a limited amount of information about the guidance function can be found in the latest editions of the FMS reference manuals for the MD-11, A-320, A340, B-777, and B-747-400.

The state of the guidance task can be inferred by integrating information from the primary flight display, the flight mode annunciator, navigation display, and various control display unit pages. However, pilots do not receive the training required to make these complex inferences.

Control FMA Design

The design of the existing MD-11 FMA is shown in Figure 1. The two main Speed Control modes are PITCH and THRUST. In a PITCH speed control mode, changing the pitch of the airplane, with a constant thrust setting controls the airspeed.

The Altitude Control mode can be viewed as the converse of the Speed Control mode. Figure 1 shows speed as controlled by pitch, which therefore leaves altitude at a constant Climb Thrust setting while climbing to the altitude target. If speed were controlled by thrust, the altitude target would be reached by varying the pitch.

An example of this is a Vertical Speed climb, which specifies the rate at which the airplane climbs and holds a target airspeed by varying thrust. These annunciations are presented in combinations. Possible annunciations for descent are either “PITCH” and “IDLE,” or “THRUST” and “V/S.” The combinations “PITCH” and “PROF,” or “THRUST” and “IDLE” will never be seen. These combinations of annunciations may not be exclusive. For example, “PITCH” and “IDLE” are used to annunciate 3 different aircraft behaviors.

Guidance FMA Design

The Guidance FMA presents the automated vertical flight mode information differently. Instead of having two modes that give information about how the aircraft is being *controlled*, which require a translation to interpret the behavior of the aircraft, the Guidance FMA uses one annunciation that describes the overall vertical behavior of the aircraft. The behavior names simplify the pilot’s task by eliminating the transformation from the

this overall behavior name is one of the following:

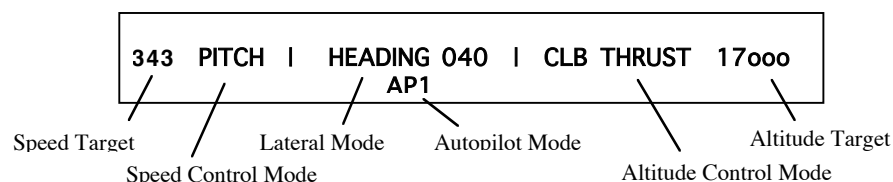
- **Climb**
- **Climb Intermediate Level**
- **Cruise**
- **Descent**
- **Early Descent**
- **Late Descent**
- **Descent Intermediate Level**
- **Descent Overspeed**

Most of these labels have an intuitive meaning to pilots, but a few require training a deeper understanding of the vertical guidance system. In these cases, if the pilot does not understand the meaning of the annunciation, it is difficult to ignore.

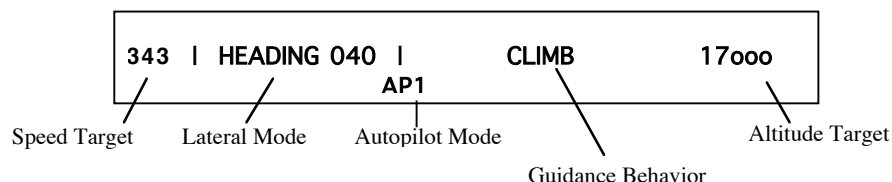
Another benefit of the Guidance FMA behavior label is that the pilot only has to view the FMA to find out what mode of operation the system is in. With the existing FMA, the pilot knows that the plane is in descent when the speed mode is in idle, but there is no information provided as to whether the plane is short or long of the path. To find this information, the pilot has to go to the performance page on the CDU and monitor the path error information. With the Guidance FMA, either a “Late Descent” or an “Early Descent” display provides that information directly.

Knowing the behavior name also assists pilots with predicting the next vertical mode because of the generally accepted sequence of events during a normal flight. Typically, Climb will go to Cruise or Climb Intermediate Level. Climb Intermediate Level, will then proceed to Climb

Existing FMA



Guidance FMA



control mode information to the aircraft behavior. Under normal automated operations,

once the airplane is cleared to a higher altitude.

Diagrams showing the existing MD-11 FMA and the guidance model. Note: Presentation on the Primary Flight Display is white or magenta text on black background.

Method

An experiment was conducted to evaluate both a new Flight Mode Annunciator and a training package to accompany the new display.

The study used three conditions.. For the “Control” condition, pilots flew the simulation without training and with the existing MD-11 FMA . The second condition, “Training”, participants completed a training program on vertical guidance techniques. This training explained how to read current FMA displays and how to infer the behavior of the airplane from the displayed information. The third condition, “Display”, participants completed the training program and then flew the scenario with the new Guidance FMA display. The control and training groups used the existing MD-11 FMA for their flight scenario.

Experimental Subjects

Eleven of the twenty-seven MD-11 pilots who participated in the study were Captains. All participants were current MD-11 pilots with at least one year of MD-11 experience. Participants were randomly assigned to conditions.

Training

Participants were given a tutor that was developed to provide an overview of the vertical navigation concepts, an introduction to the operational procedures for normal operations and to increase understanding of the MD-11 system (Feary et al., [3]).

Experimental Flight

A line-oriented flight scenario was developed to test pilot understanding. The flight was from Portland to Seattle and took advantage of the Seattle FMS transition into runway 16R. For each flight, the pilot was designated as the Pilot Flying, while the experimenter was the Pilot Not Flying and source of Air Traffic Control Information. The pilot was instructed at the beginning of the flight to keep the system in full automatic mode for as long as possible enroute. The experimenter set up the airplane configuration and the FMS for departure.

The simulator was stopped at eight points during the flight. At each of these points 3 types of questions were asked to measure pilots understanding of the avionics. The questions consisted of:

- Select the targets and behaviors which best describe the current situation of the airplane.
- Select the targets and behaviors which best describe the future situation of the airplane.

- What will the FMA display next?

At each stop, pilots were asked to identify the origins of the current speed and altitude targets for the current situation and for the next event in the scenario.

An FMA Template device used a series of push/pull slide rules so that pilots could construct the FMA for the next flight event in the simulation. To do this, pilots moved the scales up or down until the correct word or value appeared in the window.

Results

Performance scores were 91% correct for the Guidance FMA Condition, 86% for the Training condition, and 79% for the Control condition (added over all stops, higher number indicates more answers correct). Therefore, pilots in the Guidance FMA condition could predict the future state of the avionics better using the FMA Template than could the Control or Training conditions. Pilots in this condition had a better understanding of the avionics and used the displayed information to help them to predict what the future behavior of the aircraft. The difference between the Training group and the Control group was not significant.

The flight quiz data showed significant differences when looking at all of the categories combined. The Guidance FMA group showed better performance across these measures, which supports the hypothesis that the understanding of the vertical guidance procedures was enhanced with the Guidance FMA and with training.

Pilots were also asked to describe the current and next situations in terms of altitude target, speed target, and airplane behavior. The summaries for the current situation quiz showed that the composite index data (addition of altitude, speed and behavior scores) and the behavior data were significantly different when comparing the Guidance FMA group to the Control group. Mean scores for the three groups (Guidance-FMA, Training, and Control) on the composite index were 80%, 70%, and 64%, respectively.

For the next/future situation quiz, pilots in the Guidance FMA condition performed better than pilots in the Control group. On the composite index for the next situation flight quiz, pilots in the Guidance-FMA condition scored 83%, pilots in the Training condition scored 77%, and pilots in the Control Group scored 79% correct. This indicates that groups that had the display and training were more accurate at predicting what the avionics behavior than the control group.

Pilots in the Display condition were asked to rate the Guidance FMA in comparison to the existing MD-11 FMA on seven rating scales. Results indicated an overwhelming acceptance of the new display. Pilots felt the information was directly usable, helped to understand the current modes, and helped them to feel more confident about what the avionics was doing. Most pilots reported that they would like to see the Guidance FMA on the MD-11.

A few of the pilots in the study did feel slightly uncomfortable with removing the thrust and pitch annunciations from the speed FMA. Some of this discomfort may be accounted for by familiarity with the speed mode annunciation, but it was not elaborated. Further investigation is required to determine if there are situations during mixed mode (i.e. autopilot on/autothrottle off) flight for which the speed mode annunciation would aid understanding of the aircraft behavior. All of the other comments were positive.

Discussion

The Guidance FMA emerged as the superior condition in this study. Looking at the objective data, pilots in this condition could describe the current behavior and predict the next mode of operation better than the control group for normal, automated operations. Pilots in the Guidance FMA group were also better at constructing the next FMA when compared to the control group. The combination of training the pilot on what the vertical navigation system is doing and then displaying that information resulted in the best demonstration of pilot knowledge of the three groups. This may be a reflection of better understanding the avionics, more descriptive annunciation, or both, given the types of questions that were asked.

The data obtained from the subjective questionnaire showed that pilots liked the display stating that it was easier to understand what the airplane was doing and to predict what the next FMA would look like. They also felt that the Guidance FMA was usable and made them more confident in their understanding of the avionics, while reducing automation surprises during normal automated operations.

Pilots in the Guidance FMA condition had significantly less experience in the airplane than did pilots in both the training and control groups. Although the groups were randomly assigned, there may have been larger differences between the conditions if this coincidence had not occurred.

It is not clear how much training adds to the pilots understanding of the avionics from the current experiment. There were trends for training being a positive influence, but this was not statistically significant as calculated with post-hoc, pair-wise comparison tests. For each of the measures of understanding, the display group was significantly better, with the training group having a higher means than the control group. This indicates that both are necessary to really make an impact on the pilot. It is not enough to train pilots in the operation of the airplane, they must also have a display that relates this knowledge back to the task.

In the Display condition, pilots had a higher level of understanding of the avionics for both current and projected airplane behavior.. This understanding also can be obtained earlier in the learning curve for the airplane. These findings suggest that improved results may also be found for abnormal conditions, including automation failures, semi-automated, and mixed-mode flight, but this will need to be further investigated.

The findings also help the pilot to better understand the three questions posed by Wiener [1]: "What is it doing?" "Why did it do that?" and "What will it do next?" These three questions were the most frequent heard in glass cockpits by pilots trying to figure out how the avionics were operating. The first question relates to the present condition of the airplane, the second to how it got into that condition, and the third to a future state of flight. Our study showed that by training pilots and giving them the Guidance FMA, they were better able to answer these questions. This level of understanding could be further enhanced with additional situation description aids, such as Vertical Profile Displays. The more knowledge that pilots have about the avionics, the less chance for an automation surprise and a greater chance for the pilot to feel that they understand what is happening at all times and to be comfortable with the monitoring task that they are performing in automatic flight options.

References

1. Wiener, E.L. (1989). *Human factors of advanced technology ("glass cockpit") transport aircraft*. (NASA Contractor Report No. 177528). NASA Ames Research Center . Moffett Field, CA
2. Sarter, N. & Woods, D. (1992). Pilot interaction with cockpit automation: Operational experiences the Flight Management System.

International Journal of Aviation Psychology,
2(4), 303-321.

3. Feary, M., Alkin, M., Sherry, L., McCrobie,
D., Palmer, E., Polson, P., and McQuinn, N.
(1998). *Aiding Vertical Guidance
Understanding*. (NASA Technical

Memorandum No. 1998-112217). NASA Ames
Research Center. Moffett Field, CA.

4. Abbott, T.S., & Rogers, W.H. (1993).
Functional Categories for Human-Centered
Flight Deck Design. NASA Langley Research
Center. Hampton, VA.